Basin Acoustic Seamount Scattering Experiment (BASSEX) Data Analysis and Modeling

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LONG-TERM GOALS

In this program we are focusing on the science issues associated with long range ocean acoustic propagation in range-dependent environments. The primary goal is to understand the physics of the acoustic propagation in complex environments. Three specific propagation regimes are the focus of this work:

1.) seamount scattering,

2.) open ocean propagation and

3.) downslope propagation in a strongly range-dependent environment.

The long-term goal is understand scattering off of seamounts and island slopes and to develop algorithms for modeling the acoustic field in these severely range dependent (and azimuthally anisotropic) environments.

In the 2004 BASSEX experiment, with Chief Scientist Professor Arthur Baggeroer (MIT) and Co-Chief Scientist Dr. Kevin Heaney (OASIS), several specific areas of acoustic propagation where addressed. During the test acoustic transmissions from sources used in the SPICEX and LOAPEX experiments (PI: Dr. Peter Worcester, SIO and Dr. Jim Mercer, APL-UW), were recorded in the central Pacific using the Office of Naval Research – Five Octave Research Array. One week of this test was devoted to seamount scattering, with many receptions taken in various scattering geometries around the Kermit-Roosevelt seamount complex. A second week was spent in transit recording open ocean transmissions at ranges of 250km through 2000 km. The final week was spent off the coast of Kauai, recording the NPAL Kauai source at various ranges and bearings.

OBJECTIVES

The primary objective of this work is to measure aspects of acoustic propagation that we do not currently understand well (backscattering, effects of bottom roughness, propagation over basalt, 3D propagation, refraction and healing behind a sea-mount), to develop physical intuition from the data and formulate a numerical and theoretical approach to model such phenomena. The objective for this year’s effort has been to perform preliminary data analysis and to develop an understanding, through data-model comparisons, of where our physical intuition and understanding is lacking.

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14. ABSTRACT
The primary objective of this work is to measure aspects of acoustic propagation that we do not currently understand well (backscattering, effects of bottom roughness, propagation over basalt, 3D propagation, refraction and healing behind a sea-mount), to develop physical intuition from the data and formulate a numerical and theoretical approach to model such phenomena. The objective for this year?s effort has been to perform preliminary data analysis and to develop an understanding, through data-model comparisons, of where our physical intuition and understanding is lacking.

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APPROACH

Our proposed technical approach is a multi-stage approach to signal processing of the measured data and comparison with acoustic simulations. The first step is to apply beamforming and matched filtering to all of the data. This pass was done to determine a set of receptions that contain interesting physical phenomenon for further study. Once these sets are determined, plane wave and parabolic equation (PE) modeling of the geometry associated with these receptions is performed and a detailed comparison of the prediction (using 2D propagation) and the measurement is performed. Once this step is completed, effects of bottom roughness, shear in the sediment and 3D propagation will be studied.

WORK COMPLETED

In order to begin to investigate the physics of propagation over and around seamounts, downslope and across slope in strongly 3D environments, an approach to sorting through the vast data-set is required. A simple signal processing approach to characterize most of the relevant information was developed. This processing was applied to every reception from the BASSEX cruise (over 800 receptions). The processing steps included:

- Single Element Spectrogram (Frequency/Geo-time)
- Conventional Broadband Bearing Time Record (Beam Power/Geo-time)
- Single Element Matched Filter (Arrival Time/Period#)
- Doppler Power Search (Arrival Time/Doppler)
- Single Period Matched Filter (Arrival Time/Phone #)
- Beamformed Matched Filter (Arrival Time/Beam #)
- Main Beam Matched Filter (Arrival Time/Period#)

An example of this processing approach applied to a SPICE transmission received just as the R/V Revelle was over the Kermit-Roosevelt seamount is shown in Figure 1.

The two SPICE source receptions are clear in the single phone spectrogram, as well as in the Conventional Beamformer output. The upper Right panels show the two matched filter responses for a single element and the single element SNR is excellent. There is some m-sequence cross-talk, which is to be expected. What is significant about this reception is that in the lower right panels, which are Arrival Time vs. Beam, reflections from the below the ship (interpreted as sound coming up from below after reflecting off the seamount) are clearly visible after the main arrival.

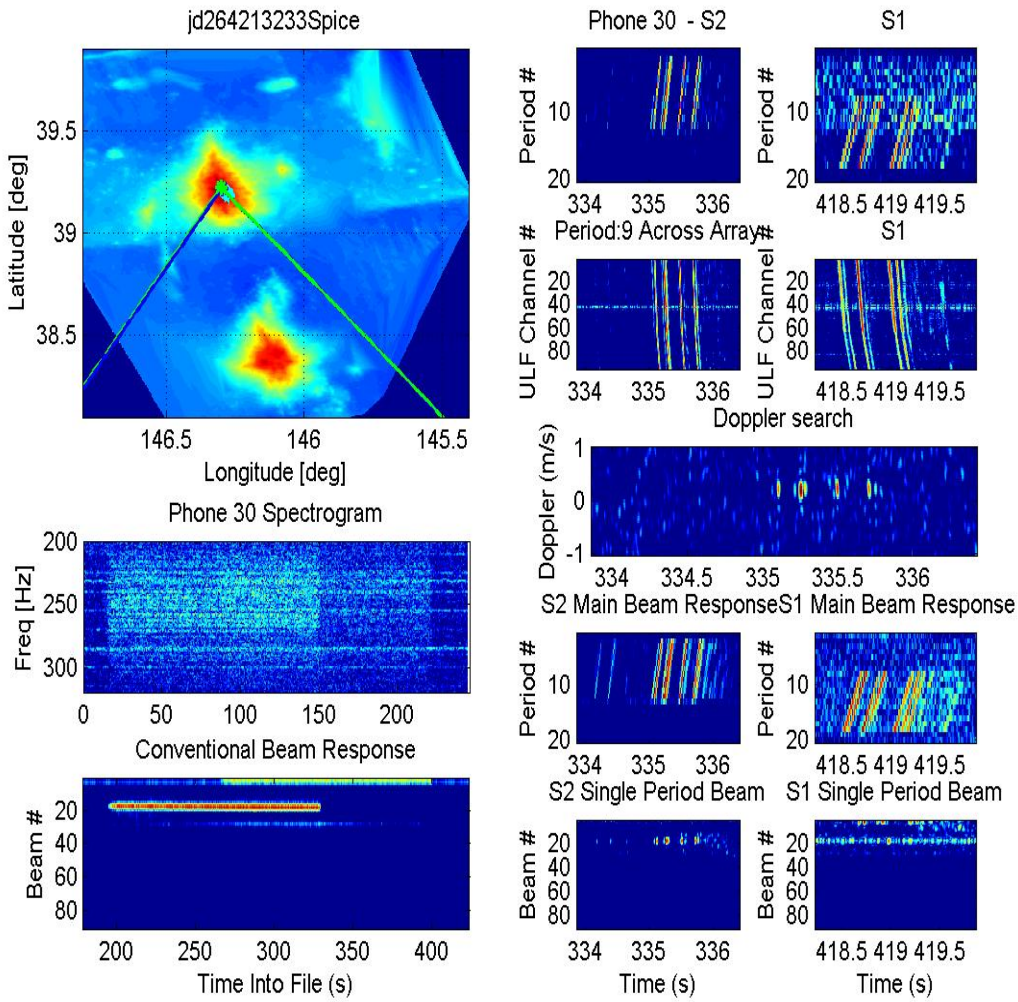

Figure 1. BASSEX Processing for SPICE Transmission JD264213233 – a SPICE transmission received as the R/V Revelle crossed the Kermit Roosevelt Seamount.

The final set of receptions were taken near the Kauai source. An example of the processing results for a very short range transmission are shown in Fig. 2.

The striations in the single element spectrogram are characteristic of shallow water propagation. As the ship approaches the source (moving in from 6 to 3 km during the transmission period) the angle of arrival of individual rays changes. The Doppler as well as angle of arrival of the higher rays relative to the direct arrival is clear in the lower right panel as well as in the Doppler search. This transmission will be used for geo-acoustic inversion over Island Basalt.

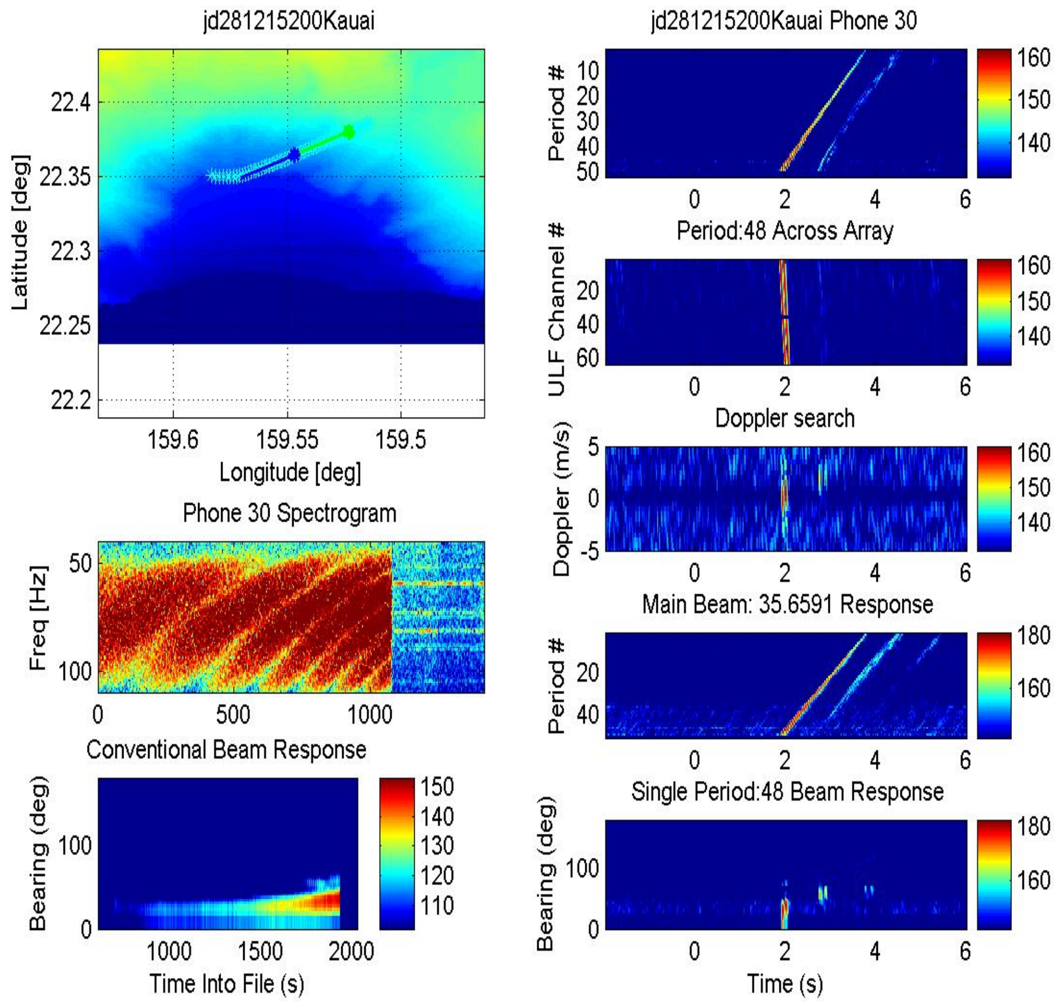

Figure 2. BASSEX Processing for NPAL KAUAI source transmission at a range of 3 km

Propagation modeling using the parabolic equation (PE) was performed to begin to study the effects of full-field propagation in the data. Systematic comparisons between the 2D PE and the measured data were then made using frequency domain adaptive and conventional beamforming. The physics being investigated is full-field in-plane propagation, geo-acoustic affects on the acoustic field, array dynamics, 3D effects and bottom roughness. By comparing the measured and the modeled beam responses and eigenspectra, each of these issues (except for 3D and roughness) can be studied. Three dimensional acoustic propagation is evident in most receptions taken near Kauai, even those a significant distance from the island.

An example of the measured 3D propagation is shown in Fig. 3.

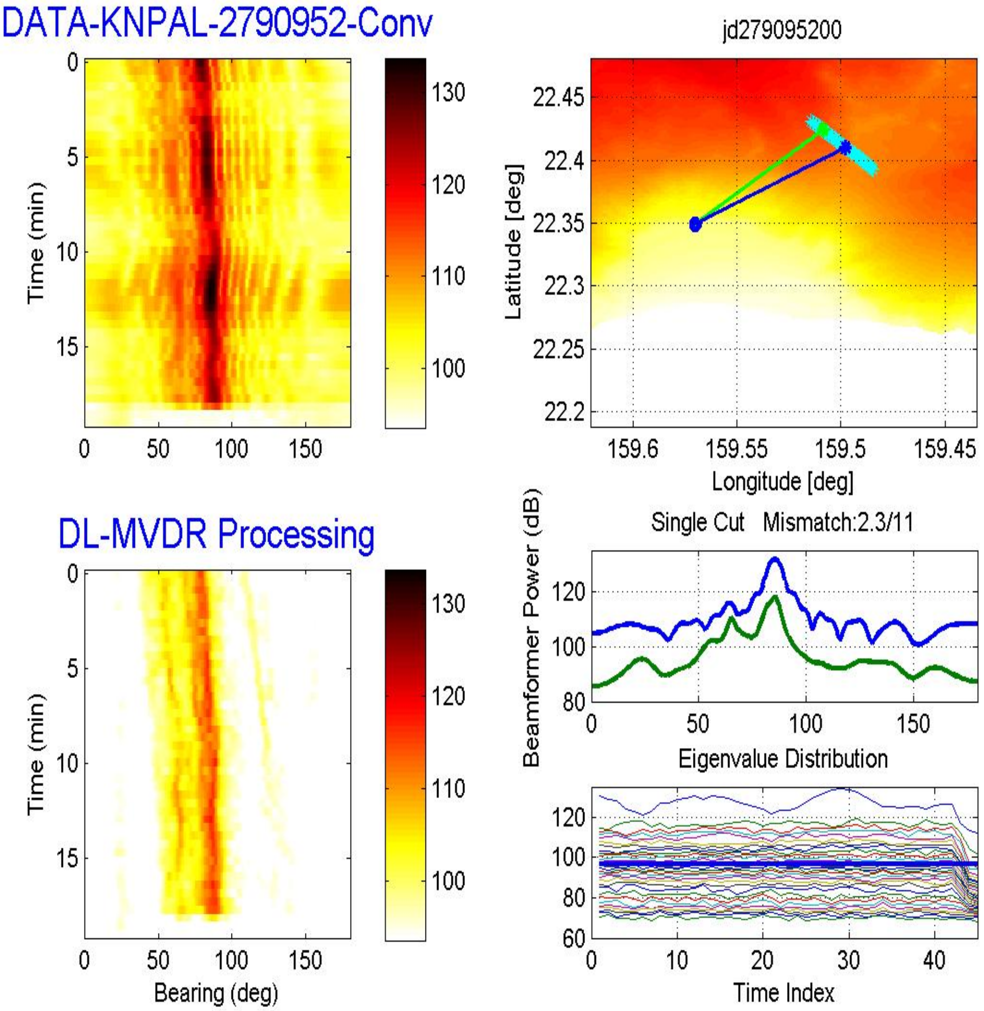

Figure 3. Processing approach applied to a broadside reception taken 10 km from the Kauai source. The upper left panel is the conventional beamformer output. The lower right is the diagonally loaded adaptive beamformer, the upper right is the geometry of the source and receiver. The next on the right is the conventional/adaptive comparison, and the right is the eigenvector spread.

In this reception the broadening of the main pulse due to 3D propagation is visible, as is the arrival of energy at 30 degrees to forward endfire of the direct path, clearly a reverberant path that is due to the 3D propagation from the island. The eigenvector analysis shows that much energy is in the direct path, but there is energy in the spreading (some of which is due to array motion and integration time effects) as well as 3D propagation. To study how much of this is due to full-field propagation and how much is due to array motion, we look at simulations (where we can take out the full-field propagation using plane wave simulations, and take out the array motion). The full-field, with motion simulation is shown in Fig. 4.

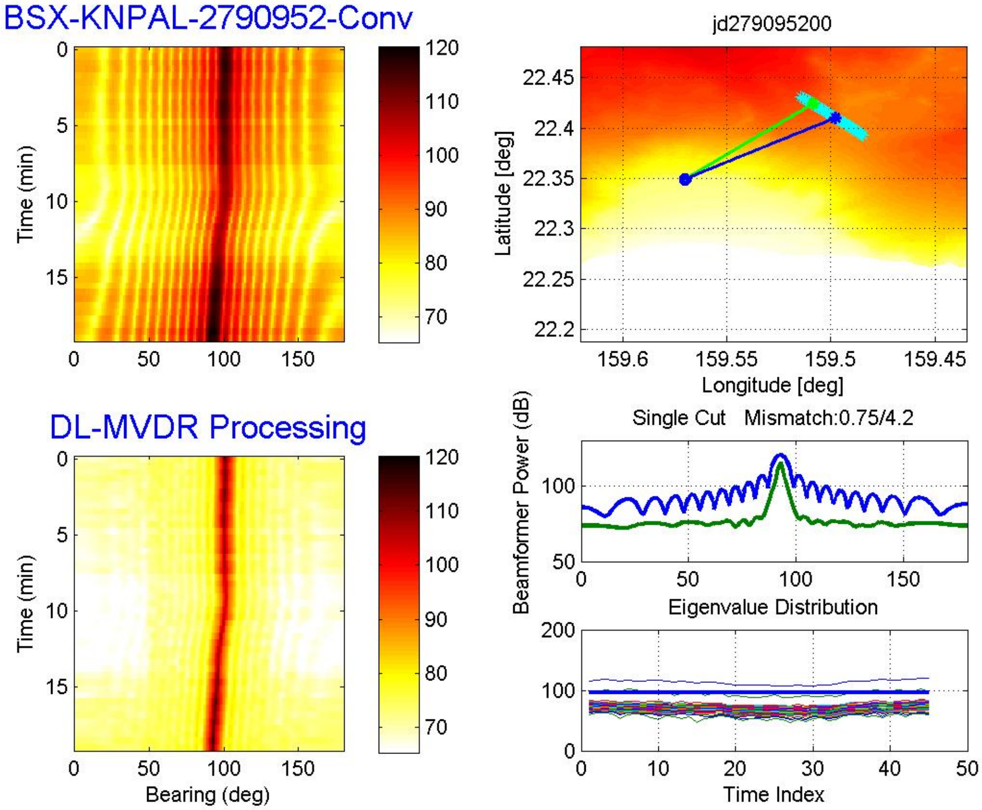

Figure 4. Processing approach applied to a broadside PE simulation taken 10 km from the Kauai source. The upper left panel is the conventional beamformer output. The lower right is the diagonally loaded adaptive beamformer, the upper right is the geometry of the source and receiver. The next on the right is the conventional/adaptive comparison, and the right is the eigenvector spread.

From the data-model comparison it is clear that only the broadening of the main lobe (symmetrically) can be explained by full field propagation, array dynamics and sampling issues. All of the energy that is not in the wind-noise is present in the first two eigenvectors, which is not the same as the data. We conclude that our propagation model is not well simulating the field in this particular example. Also note that the levels are 10 dB low, which is an indication that our geo-acoustic model is off.

RESULTS

The BASSEX04 dataset is a rich data-set for testing the fidelity of propagation models (and the limit of our understanding) for bottom interacting environments at frequencies form 75 to 250 Hz. Measurements of the acoustic shadow zone produced by seamounts with vertical extensions into the sound channel axis have been made. Measurements of 3D propagation have been made off the coast of Kauai. What is significant is that most of the receptions near Kauai (except where the path to deep water is steepest) show an indication of 3D acoustic propagation.

It is hoped that through a systematic comparison of simulations with measured data, and using the mathematics of adaptive beamforming (data covariance matrix eigenspectra) we will be able to parse out the various physical processes that remain to be studied and understood. These include: array dynamics, full-field propagation, 3D propagation, bottom roughness, propagation over shear.

IMPACT/APPLICATIONS

Many sites of potential tactical naval interest exist in the world where there is strong downslope range-dependence and the presence of rough bottoms that have shear wave propagation. With a systematic approach to data analysis, data-model comparison and theoretical development it is expected that a better capability of modeling acoustic propagation in this difficult environment will be arrived at.

RELATED PROJECTS

The SPICEX and LOAPEX experiments where conducted at the same time as the BASSEX experiment, as the other two parts of the North Pacific Acoustic Laboratory (NPAL 04) sea-test. The SPICEX experiment transmitted broadband signals with a center frequency of 250 Hz from two source moorings located a distance of 500 and 1000 km away from a vertical line array mooring. The science to be investigated during this test is the scattering of acoustic energy in the mixed layer. An understanding of the combination of acoustic scattering in the mixed layer, and mixed layer oceanography is sought through this data set. The LOAPEX experiment transmitted broadband signals centered at 75Hz from ranges of 50, 250, 500, 1000, 1600, 2300, 3200 km to the same vertical line array. An understanding of the dependence upon range of the effects of internal wave scattering is sought through this data set.

PUBLICATIONS

[1] Kevin D. Heaney, Downslope Propagation Measurements from the NPAL Kauai Source, *J.of the Acoust. Soc. Of America*, 117 (3) 1635-1642, 2005

[2] Michael D. Vera, Kevin D. Heaney and the NPAL Group, The effect of bottom interaction on transmissions from the North Pacific Acoustic Laboratory Kauai Source. *J.of the Acoust. Soc. Of America*, 117 (3) 1624-1634, 2005

[3] A.B. Baggeroer and Kevin D. Heaney, *Forward scattering from the Kermit-Roosevelt seamount complex during the BASSEX-LOAPEX-SPICEX experiments,* Proc. Of Underwater Acoustic Measurements Conference, Heraklion, Crete, Greece, 2005. pp 257-263

[4] Kevin D. Heaney, A.B. Baggeroer, Kyle M. Becker, Eddie Scheer and Keith Vonderheydt, *Range Dependent Propagation off a seamount (BASSEX 2004),* Proc. Of Underwater Acoustic Measurements Conference, Heraklion, Crete, Greece, 2005. pp 257-263